Papers

Formation and species composition of stormcast beach wrack in the Gulf of Riga, Baltic Sea*

doi:10.5697/oc.56-4.673
OCEANOLOGIA, 56 (4), 2014.
pp. 673–695.

KEYWORDS
Beach wrack
Waves
Currents
Storms
Hydrodynamic modelling
Biodiversity
Macrovegetation

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Received 25 November 2013, revised 10 April 2014, accepted 23 April 2014.

Abstract

The aim of the study was to investigate hydrodynamic effects on the formation of beach wrack at three locations in the northern Baltic Sea and to quantify the differences between the composition of species found in the beach wrack and in the

* The study was supported by the EU Life+ project MARMONI 'Innovative approaches for marine biodiversity monitoring and assessment of conservation status of nature values in the Baltic Sea', ESF grant No. 8980, Estonian target financed project SF0180104s08 and Institutional research funding IUT2-20 of the Estonian Research Council.

neighbouring sea. Hydrodynamic measurements and modelling indicated that the beach wrack was mostly of local origin and that it was formed during high sea level and wave events. Comparison of the methods of beach wrack sampling and seabed sampling (diver, underwater video) demonstrated that beach wrack sampling can be considered an alternative tool for describing the species composition of macrovegetation in near-coastal sea areas. Although the hydrodynamic variability is greater in autumn and more biological material is cast ashore, the similarity between the two sampling methods was higher in spring and summer.

1. Introduction

Wave action, tides and aperiodic water level fluctuations are among the most important factors for the development and distribution of macrovegetation in coastal sea areas (Kautsky & van der Maarel 1990, Kautsky et al. 1999, Boller & Carrington 2006). Besides the direct influence of physical disturbance, the site-dependent hydrodynamic conditions act on benthic communities through turbidity-related light restrictions and by structuring the bottom substrate (Herkül et al. 2011, Kovtun et al. 2011). Most macroalgae and all aquatic vascular plants are attached by holdfasts or roots to the seabed. However, spring tides, strong currents or waves during stormy weather conditions may rip vegetation off its substrate and cast it on to the shore (Lobban & Harrison 1994, Ochieng & Erftemeijer 1999). Detached macrovegetation that is washed ashore and accumulated on a beach is called beach wrack, beach cast, stormcast, wrack band or beach strand. Beach wrack can also be formed from unattached, drifting macroalgae; their mass occurrence is often promoted by elevated nutrient levels (e.g. Kirkman & Kendrick 1997). The wrack line is a strip of debris that usually runs parallel to the edge of the water and marks either the high tide or storm swash line. This wrack line can consist of a mixture of both natural material and man-made litter.

Hydrodynamics plays a major role in the process of detachment, transport and accumulation of macrovegetation. Wrack deposition is highly variable depending on beach type, nearshore hydrodynamics and buoyancy characteristics of the wrack; in a curved or indented coastline, the beach wrack and detritus distribution may be rather patchy (Orr et al. 2005, Oldham et al. 2010). As the wrack particles dry on the shore, the biological material becomes more buoyant and can also be moved back to sea during the next high water event that covers the wrack. The buoyancy of different macrophyte species varies: some species (e.g. *Fucus vesiculosus* L.) can be cast ashore more easily than others. Furthermore, the material may originate in nearby areas but can also be carried as drifting algal mats from distant locations (Biber 2007). Over a period of about one year beach wrack decays and becomes detritus. Regarding persistence, some species decompose faster than others. Although the biomass of species with tender thalli may decrease rapidly, fragments of specimens remain in the wrack for several months, which allows the species to be identified (Jędrzejczak 2002a,b). Beach wrack is an important component of the food web and nutrient load for coastal ecosystems. Beach casts provide an ideal environment for microorganisms, amphipods and insects. A number of articles describe how beach wrack, an allochthonous input of organic matter, directly enhances the abundance of beach fauna through the provision of food and habitat (Pennings et al. 2000, Dugan et al. 2003, Ince et al. 2007) or by fertilising foredune vegetation (Gonçalves & Marquez 2011). Beach wrack accumulations can filter out wave effects, contributing to beach stability (Ochieng & Erftemeijer 1999). Beach wrack also plays an important role in the building of new dunes by capturing sand and seeds, allowing new dunes to form. On the other hand, trapped detritus accumulations may result in the temporary creation of anoxic conditions underneath. On recreational beaches, decaying beach wrack is often perceived as a kind of 'pollution', which smells bad and promotes insects and bacteria, and its removal is therefore sometimes an important management task (Filipkowska et al. 2009, Oldham et al. 2010, Imamura et al. 2011).

Some of the very first data on macrophyte species occurring in the eastern Baltic Sea area were collected from beach wrack (von Luce 1823, Heugel & Müller 1847, Heugel 1851/52, Müller 1852/53, Lepik 1925). Although equipment like hooks, rakes or grab samplers was used to sample specimens from the nearshore, beach wrack was still an important source of data for such studies. Since 1959, SCUBA diving has been widely used to collect macrovegetation data from the Estonian coastal sea (Pullisaar 1961). Nowadays, in addition to expensive and time-consuming diving, underwater video cameras and remotely operated underwater vehicles are also used for observing and collecting samples from macrovegetation communities. In turn, beach wrack studies have become rare. The composition and seasonality of stormcast in the Baltic Sea has previously been studied in Puck Bay (Kotwicki et al. 2005) and in the Väinameri area (Kersen & Martin 2007). The importance of beach wrack also becomes evident when one wishes to know how the composition of beach wrack reflects the coastal sea biodiversity. The concept of using stormcast as a simple method for biodiversity assessment has been previously tested on shelled molluscs by Warwick & Light (2002).

Together with water quality variables, hydrobiological parameters describing seabed vegetation are often included in assessments of the status of coastal environments. Biological diversity is one of the descriptors that should be assessed in connection with the implementation of the EU Marine Strategy Framework Directive and the general goal of achieving a good environmental status of marine waters (Torn & Martin 2011). Over time, a huge number of indices have been developed (e.g. Heip & Engels 1974, Magurran 1988, Desrochers & Anand 2004). However, no commonly agreed procedures and methods currently exist for the assessment of marine biodiversity.

Within the EU LIFE+ funded project MARMONI ('Innovative approaches for marine biodiversity monitoring and assessment of conservation status of nature values in the Baltic Sea'), a new method called the Beach Wrack Macrovegetation Index (unpublished) is being developed. As the first development stage, the current study investigates the suitability of beach wrack data for describing the biological diversity of the macrovegetation in the coastal sea and evaluates the role of hydrodynamics in the formation of beach wrack in the Baltic Sea. Since collecting beach wrack samples is much easier than fieldwork that involves diving, the method we are outlining here may provide a cost-effective alternative. Hydrodynamic modelling (hindcasts and forecasts of nearshore currents and waves) may explain in which part of the sea area the wrack material originates and how storm surges and high wave events are linked with the formation of beach wrack strips. Hence, the aims of the present study are (1) to describe the influence of hydrodynamic variations on the formation of beach wrack and (2) to test the differences between the species composition of beach wrack and nearshore benthic communities as sampled by SCUBA diving or underwater video.

2. Study area

The study area, the brackish-water Gulf of Riga, is considered to be one of the most eutrophic basins in the Baltic Sea. Therefore the biodiversity, water quality and hydrodynamic processes of the area have been continuously studied (Kautsky et al. 1999, Kotta et al. 2000, Martin 2000, Martin et al. 2003, Suursaar & Kullas 2006, Kovtun et al. 2011). At the present time, 531 species of macroalgae, aquatic vascular plants, charophytes and bryophytes are recorded in the Baltic Sea (HELCOM 2012). Typically for most brackish water systems, the number of marine species decreases with the salinity gradient. Along this salinity gradient, the basin of the Gulf of Riga has one of the lowest macrovegetation species diversities.

The Gulf of Riga has a surface area of 17 913 km^2, a volume of 406 km^3, a maximum depth of 52 m and an average depth of 23 m. The average salinity in the gulf is 5.6. Outside the straits, the currents in the practically tideless Estonian coastal sea are meteorologically driven and generally

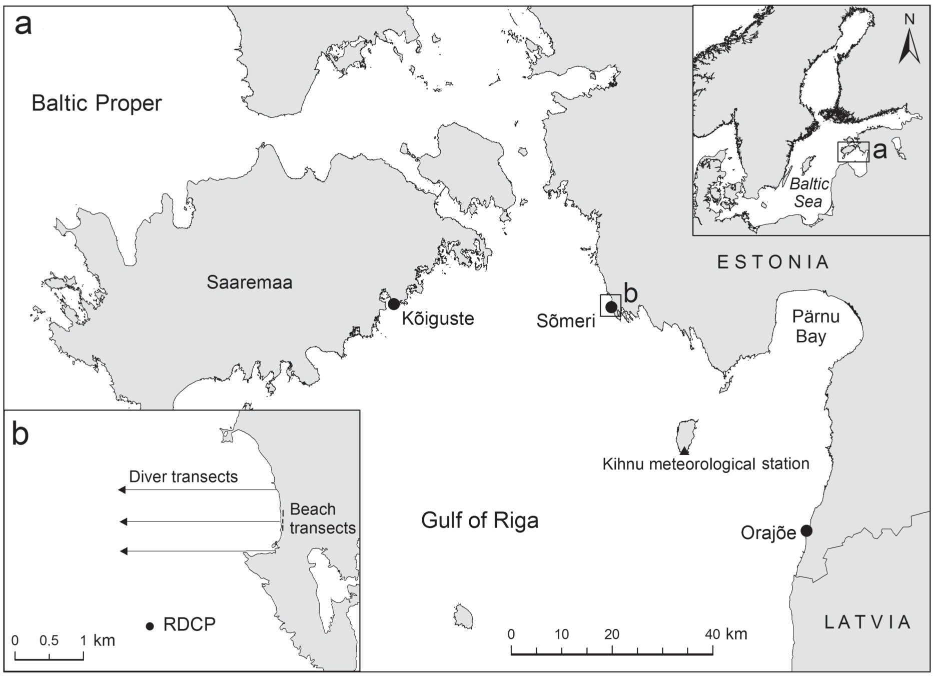

Figure 1. Study area. In figure b, the location of the RDCP instrument and the schematic location of the diver/video and beach transects in the Sõmeri area are shown as an example

neither persistent nor strong (Suursaar et al. 2012). Because of the semi-enclosed configuration of the study area and the presence of some shallow bays exposed to the direction of the strongest expected storm winds, the sea level variability range is up to 4 m in Pärnu Bay and about 3 m elsewhere in the gulf (Jaagus & Suursaar 2013). As a result of the small area of the gulf (140×150 km^2), significant wave heights (Hs) may reach 4 m when a storm wind blows from the direction of the longest fetch for a particular location (Suursaar et al. 2012). Long, relatively calm periods are interspersed with occasional wind and wave storms without a noteworthy swell-component. In general, the swash climate associated with low-energy dissipative beaches (with wide surf zones and flat beach profiles) supports an abundant coastal life (Lastra et al. 2006). As the beach type changes towards reflective conditions with short surf zones, coarse bottom substrates and steep slopes, the increasingly inhospitable swash climate gradually excludes sensitive species. The specific study locations at Kõiguste (58°22′N, 22°59′E), Sõmeri (58°21′N, 23°44′E) and Orajõe (57°57′N, 24°23′E; Figure 1) are predominantly low-energy beaches with low-lying hypsometric curves. The bottom substrate varies between sandy and morainic (Martin 1999). According to earlier studies, the three areas showed slightly different patterns of phytobenthic communities. While the Kõiguste area was characterised by high coverage and biomass, the other areas had a lower coverage and biomass of benthic vegetation (Martin 2000). According to previous studies, the most frequent species were filamentous algae such as *Ceramium tenuicorne* (Kützing) Waern, *Polysiphonia fucoides* (Hudson) Greville, *Pilayella littoralis* (Linnaeus) Kjellman and *Battersia arctica* (Harvey) Draisma, Prud'homme & H. Kawai in the Gulf of Riga (Martin 1999). Recently, the filamentous red alga *P. fucoides* occurred most frequently and with high coverage in all the areas studied (Kersen 2012).

3. Material and methods

3.1. Macrophyte sampling

Sampling of the seabed phytobenthic community was carried out in three areas (Kõiguste, Sõmeri and Orajõe) in the northern Gulf of Riga (Figure 1) in May, July and September 2011. In each area, macrophyta were observed along three parallel transects placed perpendicularly to the shoreline with a distance of 500 m between the transects. The length of the transect was 2–4 km depending on the area. The depth intervals of the sampling sites along the transects were 1–1.5 m. At each depth, coverage was estimated within a radius of 2–3 m around each sampling site. Coverage was assessed as a percentage of the sea bottom covered by vegetation or a certain species within the extent of the sampling site. Along the transects, the total coverage of the macrovegetation community, coverage of individual species and character of substrate were registered visually by the diver or recorded with an underwater video camera. Observations were carried out to the deepest limit of vegetation on the transect. In the Kõiguste and Sõmeri areas, 8–10 observations were made along the transects (the deepest vegetation at 10 m depth). In the Orajõe area the number of observations per transect was 7–9 (the deepest vegetation at 8.3 m depth).

Paired with the sampling of seabed phytobenthic community in May, July and September, beach wrack samples were also collected in April, June, August and October (Table 1). Wrack samples were collected from three transects parallel to the shoreline in each area. The distance between the transects was about 60 m. The lengths of the transects were 5 m and five samples were collected from each transect. The samples were collected using a 20 cm $\times$ 20 cm metal frame at a distance of 1 m from one another. Each individual frame sample served as a sampling unit in further statistical analyses. This design (3 transects and 5 samples per transect) resulted in 15 samples per area in each month. Distances from the water edge [m], thickness [cm] and coverage [%] of the wrack layer inside the sampling frame were measured. The freshest beach wrack closest to the sea was always chosen for sampling. As a rule, older, more or less decomposed wrack strips were located higher on the shore. In April, only three samples were collectable from fresh beach cast material. As the rest of the samples included old material cast ashore during the previous autumn before the sea froze up, the April data were excluded from further quantitative analyses.

The collected material was packed and kept frozen. In the laboratory, the species composition in each sample was determined. As wrack specimens were often fragmented and detailed identification was impossible, morphologically very similar species were treated as one group. The filamentous brown algae *Ectocarpus siliculosus* (Dillwyn) Lyngbye and *Pilayella littoralis* (Linnaeus) Kjellman were not separated. All characeans except *Tolypella nidifica* (O. F. Müller) Leonhardi were determined as *Chara* spp. Higher plants with similar morphology such as *Zannichellia palustris* L., *Ruppia maritima* L. and *Stuckenia pectinata* (L.) Börner were treated as one group. The biomasses of *Fucus vesiculosus* L. and *Furcellaria lumbricalis* (Hudson) J. V. Lamouroux and the rest of the sample were separated and weighed after drying at 60°C to constant weight. Biomass (grams dry weight) was calculated per square metre [g d.w. m^{-2}]).

3.2. Meteorology and hydrodynamics

In order to study possible relationships between biological beach wrack findings and coastal hydrodynamic conditions, special field measurements and a hydrodynamic modelling study were carried out. A Doppler effect-based oceanographic instrument RDCP-600 manufactured by Aanderaa Data Instruments was deployed by divers to the seabed at two locations, off Sõmeri and Kõiguste. Near the Sõmeri Peninsula (58°20′N 23°43′E, less than 1 km from the closest phytobenthos transect and about 3 km

Table 1. Wrack sampling dates and codes (see Figs. 2, 3) at the three study sites in 2011

Code	Kõiguste	Sõmeri	Orajõe
I	20 April	20 April	24 April
II	18 May*	19 May*	20 May*
III	17 June	14 June	24 June
IV	19 July*	24 July*	23 July*
V	12 August	11 August	18 August
VI	11 September*	18 September*	17 September*
VII	15 October	14 October	14 October

* denotes concurrent sampling of seabed communities.

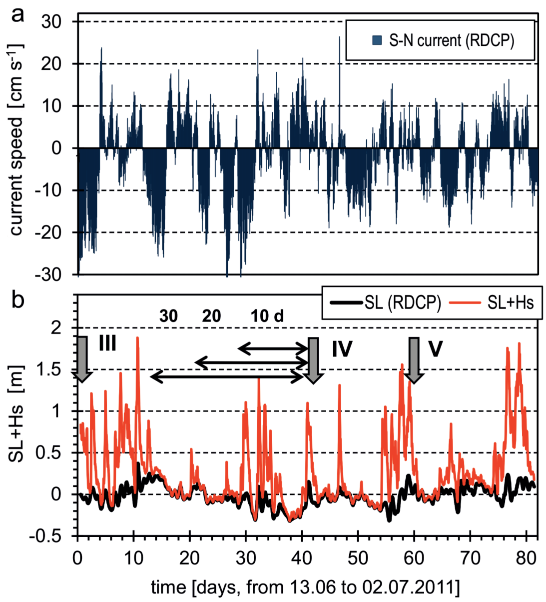

Figure 2. RDCP based hydrodynamic measurements at Sõmeri (1.5 km off the coast) from 13 June to 2 September 2011. The northward alongshore sub-surface current is positive in (a). RDCP measured sea level (SL) and the combined sea level and significant wave height (SL + Hs) together with biological sampling periods marked in the figure (b) with arrows (III, IV, V, see also Table 1). 10-, 20- and 30-day assessment periods for hydrodynamics are shown as an example for the study period IV (b)

from the beach wrack sampling transects), the upward looking instrument recorded currents from 13 June 2011 to 2 September 2011. The RDCP-600 is also equipped with temperature, conductivity, oxygen and turbidity sensors, and a pressure sensor enables the measurement of sea level variations and waves above the instrument. Significant wave height (Hs), which is the most commonly used wave parameter, represents the average height of 1/3 of the highest waves and is roughly equal to the visually observed 'wave height'.

At Sõmeri, 81 days of hydrodynamic measurements covered three biological sampling periods (Figure 2). In order to obtain hydrodynamic forcing data for the whole year of 2011, the wave parameters were calculated using a locally calibrated SMB-type wave model, and nearshore currents and sea level variations were calculated using a 2D hydrodynamic model (see Suursaar et al. 2012 and Suursaar 2013 for model calibration and validation details). Wind stress for forcing the models was calculated from the wind data measured at the Kihnu meteorological station and a full year hydrodynamic hindcast at 1 h intervals was obtained. Operated by the Estonian Environment Agency (previously known as the Estonian Meteorological and Hydrological Institute), the Kihnu station has unobstructed offshore wind conditions (Suursaar 2013). It is centrally located between the three study sites, 27 km from Orajõe, 30 km from Sõmeri and 55 km from Kõiguste.

At Kõiguste and Orajõe, no hydrodynamic measurements were carried out strictly in line with the hydrobiological samplings. At Kõiguste, the RDCP was deployed from 2 October 2010 to 11 May 2011, which allowed the wave model to be calibrated and validated specifically for that location, therefore enabling a high-quality hydrodynamic hindcast (see Suursaar et al. 2012). Fine tuning of the wave model was impossible and the wave hindcast is presumably less precise at Orajõe. However, the 2D hydrodynamic model, once validated (against Pärnu tide gauge sea levels and Sõmeri flow measurements; Suursaar et al. 2006, 2012), delivered hourly sea level and current outputs at the Kõiguste and Orajõe locations in 2011 just as well as at the Sõmeri location. The simulated sea level, wave height and current velocity time series were used to study the hydrodynamic conditions during and before the hydrobiological samplings (Table 1). In order to establish hydrodynamics-hydrobiology relationships, mean heights of sea level and significant waves, maximum wave heights and average alongshore current speeds were calculated for each location separately over three different review periods: 10, 20 and 30 days prior to each beach wrack sampling date (see Figure 2b; Table 1).

3.3. Data analysis

The differences in macrovegetation community structures between the transects, months and methods were assessed using ANOSIM (Clarke & Warwick 2001) in the statistical program PRIMER version 6.1.11 (Clarke & Corley 2006). The ANOSIM analyses were based on the Bray-Curtis similarity matrices of macrovegetation occurrence data. The test statistic R provided by ANOSIM reflects the differences in community structure between groups (e.g. transects, months or methods). An R value of 1 indicates that all samples within groups are more similar to each other than any pair of samples from different groups, i.e. there is a total separation between the groups. An R value of zero shows that similarities between and within the groups are equal, i.e. no separation between the groups exists (Clarke & Warwick 2001). According to Clarke & Corley (2006), an R value of less than 0.25 indicates that the separation between groups is negligible; an R value of 0.5 to 0.75 shows overlapping but clearly differentiable groups, and an R value over 0.75 indicates well separated groups. The calculation of R and statistical significance (p) in ANOSIM was based on a random permutation ($n = 9999$) test (Clarke & Warwick 2001). SIMPER analysis was used to describe the differences in the species composition of macrophytobenthos among the sample collection methods (Clarke 1993).

In order to study the possible selective influence of hydrodynamics on various species and quantitative aspects of beach wrack, relationships between different variables of biological beach cast (distance from water edge, coverage inside the sampling frame, biomass of key species, total biomass, species number) and coastal hydrodynamic variables (sea level together with maximum and average wave height and average alongshore current speed over the three averaging periods) were tested using Pearson correlation analysis in the statistical program STATISTICA (StatSoft 2012). The data were tested for normality and homogeneity of variances before running correlation analysis using the Kolmogorov–Smirnov test and Levene's test respectively.

4. Results

4.1. Hydrodynamic conditions of beach wrack formation

While the sea level variations in the three study sites were rather synchronous and differed by less than 10–20 cm from one another (Figure 3), the differences in wave heights were more substantial. Orajõe, featuring relatively long (up to 130 km) fetches from the west, had combined sea level-wave heights of up to 2.8 m (Figure 3d), while the south-westerly (90 km) exposed Sõmeri got 2.5 m (Figure 3a) and the south-easterly (100 km) exposed Kõiguste only 2.2 m (Figure 3c) sea level-wave heights during the same period. The combined water height reached 4 metres during the stormy period in December 2011 (Figure 3a,b), but no biological samples were taken then. The combined sea level and wave height was relatively high (at least 1.5 m above mean sea level at Sõmeri, 1.2 m at Kõiguste and 1.4 m at Orajõe) on the days of the year 145, 170–174, 255–258, 265–267, 278–284 and 330–360 (Figure 3a). The alongshore current speeds were the greatest (up to 45 cm s^{-1}) in autumn on days 280–290 and 300–360.

The currents fluctuated between north and south without any long-term preference (Figure 2a, 3b). Despite the lack of tides, meteorologically induced high sea level events occurred rather periodically, every 10–30 days. As a rule, in late autumn and during ice-free winters such events are both more frequent and violent (Figure 3). The Gulf of Riga was covered by sea-ice for the first 110 days of 2011, i.e. until April 20.

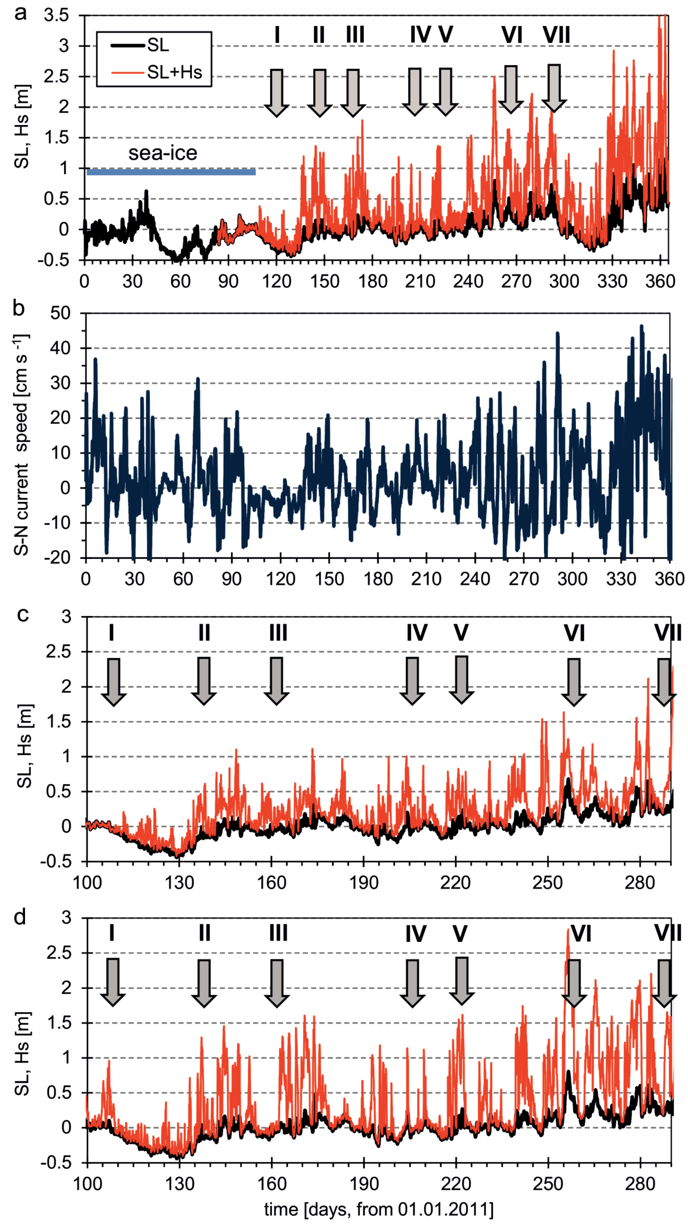

Figure 3. Modelled variations in water level (SL and SL + Hs, see also Figure 2) for the full year of 2011 (a) and for shorter excerpts (c, d) with the sampling periods (I–VII; Table 1); calculated nearshore S–N current components vertically averaged over the 10 m depth range (b). Study sites Sõmeri (a,b), Kõiguste (c) and Orajõe (d)

Usually, all the hydrodynamic assessment periods (Figure 2b) included at least one or two rough sea events. In such cases, the sampled wrack strip was formed during the last event. If the wave height prior to the last one was significantly higher, the older wrack strip was located higher up the shore and its material was not analysed. If the wave height in each next event was higher than the preceding one, the material from the different casts was mixed together while being transported to a higher level.

In general, the relationships between the hydrodynamic conditions and the structure of beach wrack obtained using a 10-, 20- or 30-day averaging period did not differ substantially (Table 2). The maximum wave height taken 10 days before the biological sampling was the best hydrodynamic correlate, which positively explained layer thickness, *F. vesiculosus* biomass (Figure 4a,b), total biomass (correlation coefficient, r, between 0.73 and 0.80 at Kõiguste, and 0.47–0.54 at Sõmeri; Table 2) and *F. lumbricalis* biomass. High wave events tended to increase the amount of beach wrack.

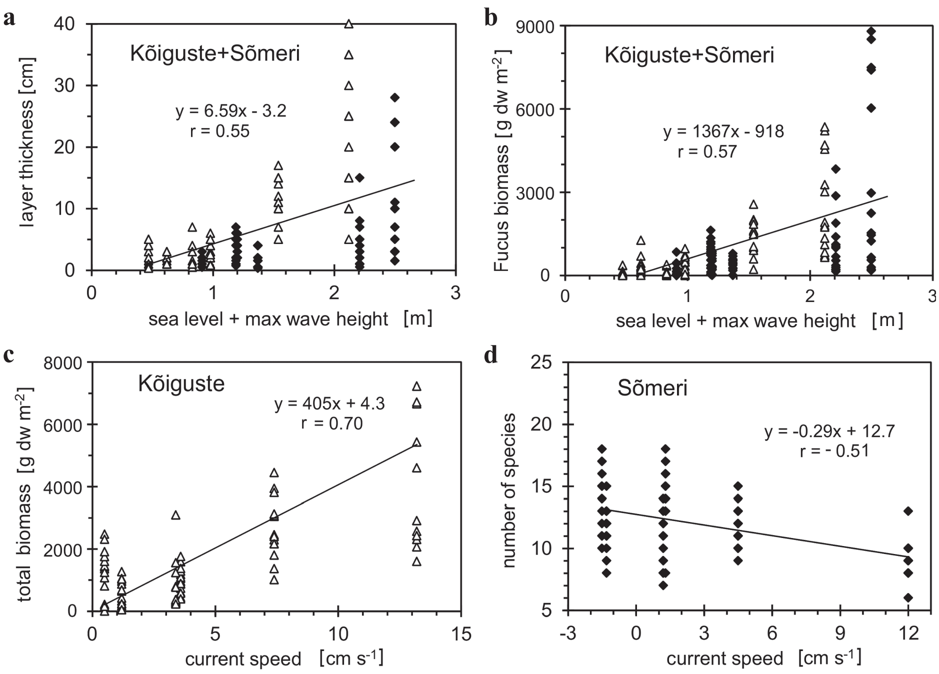

Figure 4. Some examples of regressions between the biological parameters and hydrodynamics: maximum wave heights (10 days before sampling) with layer thickness (a) and *Fucus* biomass (b) at Kõiguste (triangles) and Sõmeri (rhombuses); current speed (20 days before sampling) with total biomass at Kõiguste (c) and with the number of species at Sõmeri (d)

Table 2. Correlation between hydrodynamic parameters (mean values over three averaging periods) and biological parameters. Hm – maximum wave height plus sea level, Ha – average wave height plus sea level, C – average alongshore current speed (northward direction is positive). Statistically significant ($p < 0.05$) correlations are in bold

		30-day period			20-day period			10-day period		
		Hm	Ha	C	Hm	Ha	C	Hm	Ha	C
Kõiguste	distance to shoreline	0.13	**0.22**	0.09	0.05	0.08	−0.19	0.13	0.01	−0.08
	thickness	**0.75**	**0.64**	**0.76**	**0.75**	**0.62**	**0.78**	**0.80**	**0.72**	**0.73**
	frame coverage	**0.41**	**0.39**	**0.36**	**0.44**	**0.45**	**0.47**	**0.40**	**0.46**	**0.46**
	Fucus biomass	**0.70**	**0.62**	**0.69**	**0.71**	**0.61**	**0.71**	**0.73**	**0.68**	**0.64**
	Furcellaria biomass	**0.76**	**0.66**	**0.76**	**0.76**	**0.64**	**0.76**	**0.79**	**0.73**	**0.70**
	total biomass	**0.74**	**0.65**	**0.75**	**0.74**	**0.62**	**0.70**	**0.76**	**0.71**	**0.70**
	species number	0.00	−0.03	−0.04	0.04	0.07	0.14	0.04	0.08	0.16
Sõmeri	distance to shoreline	0.03	−0.04	0.11	0.05	0.06	**0.63**	0.09	0.02	0.20
	thickness	**0.53**	**0.25**	0.09	**0.54**	**0.40**	−0.11	**0.54**	**0.44**	**−0.35**
	frame coverage	−0.06	**−0.29**	**−0.24**	−0.00	−0.20	**0.22**	0.09	−0.07	0.17
	Fucus biomass	**0.51**	**0.28**	0.13	**0.52**	**0.42**	−0.04	**0.52**	**0.44**	**−0.30**
	Furcellaria biomass	**0.32**	0.09	0.01	**0.34**	**0.22**	0.09	**0.35**	**0.25**	−0.20
	total biomass	**0.43**	0.17	0.11	**0.45**	**0.32**	0.01	**0.47**	**0.36**	**−0.24**
	species number	**0.31**	−0.02	−0.06	**0.34**	0.12	**−0.51**	**0.32**	0.19	**−0.48**
Orajõe	distance to shoreline	−0.12	0.03	−0.13	0.04	−0.03	−0.15	0.04	−0.12	−0.20
	thickness	0.15	−0.07	**0.24**	0.02	0.05	**0.28**	0.02	0.15	0.19
	frame coverage	**−0.31**	**−0.65**	**−0.25**	−0.19	**−0.50**	−0.11	−0.19	**−0.43**	**−0.38**
	Fucus biomass	**−0.33**	**−0.46**	**−0.55**	**−0.50**	**−0.49**	**−0.50**	**−0.50**	**−0.43**	**−0.23**
	Furcellaria biomass	−0.13	**−0.31**	**−0.31**	**−0.26**	**−0.29**	**−0.25**	**−0.26**	**−0.23**	−0.16
	total biomass	0.10	**−0.22**	0.12	0.03	−0.06	**0.21**	0.03	0.03	−0.19
	species number	0.12	−0.02	**0.42**	−0.08	0.09	**0.39**	−0.08	**0.24**	**0.47**

The hydrodynamic conditions did not have any noteworthy influence on the distance of wrack from the waterline and the species number.

While the different averaging periods (10, 20, 30 days) of hydrodynamic variables had similar impacts at Sõmeri and Kõiguste, a large scatter of correlations appeared at Orajõe. The specificity of that location involves an exposed straight coastline, which does not trap the material in the same way as in the shallow and more or less enclosed bays (like Kõiguste).

In the case of alongshore currents, the high correlation coefficient indicates favourable conditions for beach wrack formation, regardless of its sign. Alongshore currents negatively influenced *F. vesiculosus* biomass, species number, layer thickness and the total biomass at Sõmeri. The negative relationship here means that the bay collects more biomass and more species when winds are northerly and the corresponding currents southward. Northward currents tend to flow past the bay. Somewhat differently, the northward currents strongly and positively influenced wrack thickness, coverage and biomass at Kõiguste. This means that positive relationships with positively (northward) directed currents exist (Figure 4d): the coastline here entraps the material transported from the south.

4.2. Comparison of the species composition of macrovegetation in coastal sea beach wrack and in the neighbouring sea

The most frequently occurring species in all areas were the filamentous algae *Cladophora glomerata* (L.) Kützing and *P. fucoides*. Both *F. vesiculosus* and *F. lumbricalis* were found in all areas with the lowest coverage in the Orajõe area (Table 3). Differences in the species composition of submerged vegetation between the three study areas were negligible (ANOSIM analysis $R = 0.057$, $p < 0.001$, $n = 227$). The species composition of attached submerged vegetation did not vary between the three parallel transects (Kõiguste: $R = 0.004$, $p = 0.333$, $n = 79$; Sõmeri: $R = 0.054$, $p = 0.035$, $n = 82$; Orajõe: $R = 0.011$, $p = 0.278$, $n = 66$).

In the Kõiguste and Sõmeri areas, *F. vesiculosus* formed the largest share of the biomass of beach wrack samples. Minor differences were detected in the species composition in beach wrack samples between areas ($R = 0.260$, $p < 0.001$, $n = 270$). Differences were greatest in October ($R = 0.700$, $p < 0.001$, $n = 45$), caused by the different frequency of occurrence of green filamentous algae and vascular plants. The Orajõe area, where vascular plants and charophytes were found only occasionally in samples, exhibited the largest differences. Species composition was not influenced by the location of the three replicate beach wrack transects along the coastline ($R = 0.040$, $p = 0.018$, $n = 90$). The composition of beach wrack samples showed small differences between the months. The occurrence rate of

Table 3. The structure of the macrovegetation in the study areas in 2011 in the months when both methods were used. M – May, J – July, S – September

Taxon	Kõiguste		Sõmeri		Orajõe	
	Submerged vegetation	Beach wrack	Submerged vegetation	Beach wrack	Submerged vegetation	Beach wrack
Chlorophyta						
Cladophora glomerata Kütz.	MJS	MJ	MJS	MJS	MJS	MJS
Cladophora rupestris (L.) Kütz.		S	MJ			
Ulva intestinalis L.	S	MJ	S	MJS	JS	JS
Phaeophyta						
Chorda filum (L.) Stackh.		S			S	
Fucus vesiculosus L.	MJS	MJS	MJS	MJS	MJS	MS
Pilayella littoralis (L.) Kjell./ *Ectocarpus siliculosus* Lyngb.	MJ	M	MJS	MS	MJ	JS
Battersia arctica (Harvey) Draisma, Prud'homme & H. Kawai	MJS	JS	MJS	MJS	MJS	MJS
Stictyosiphon tortilis (Ruprecht) Reinke	M					
Rhodophyta						
Ceramium tenuicorne Waem	MJS	MJS	MJS	MJS	MJ	MJS
Coccotylus truncatus W. & H.	M	MJS		MS		
Furcellaria lumbricalis Lam.	MJS	MJS	MJS	MJS	MJS	MJS
Polysiphonia fibrillosa Spren.						M
Polysiphonia fucoides Grev.	MJS	MJS	MJS	MJS	MJS	MJS
Rhodomela confervoides (Hudson) P. C. Silva	M	M			J	
Charophyta						
Chara spp.	MJS	MJS	MJS	MJS	MS	MJS
Tolypella nidifica Leonh.	J					
Magnoliophyta						
Zannichellia palustris L. / *Ruppia maritima* L. / *Stuckenia pectinata* (L.) Börner	MJS	MJS	MJS	MJS	J	MJS

Table 3. (*continued*)

Taxon	Kõiguste		Sõmeri		Orajõe	
	Submerged vegetation	Beach wrack	Submerged vegetation	Beach wrack	Submerged vegetation	Beach wrack
Myriophyllum spicatum L.	MJS	MJ	MJS	MJS	S	MJS
Potamogeton perfoliatus L.	J	MS	S	JS		JS
Ranunculus baudotii Godr.			J			
Zostera marina L.		MJS		MJS		MS
Bryophyta						
Fontinalis spp.						M
Xanthophyta						
Vaucheria dichotoma (L.) Martius				M		

Table 4. Differences in the species composition of phytobenthos between the two methods in the three study areas as revealed by the ANOSIM test (R statistic, sample size n). All $p < 0.01$

Area	All months		May		July		September	
	R	n	R	n	R	n	R	n
Kõiguste	0.237	124	0.181	40	0.161	44	0.421	40
Sõmeri	0.265	127	0.267	42	0.283	42	0.376	43
Orajõe	0.387	111	0.357	37	0.364	38	0.496	36

filamentous algae was lowest in September and October compared to the other sampling occasions, causing the clear separation of autumn samples.

Differences in species diversity between the areas and methods were small (Table 3). There were slight differences in species composition between the wrack samples and the material collected from the seabed ($R = 0.265$, $p < 0.001$, $n = 362$). The difference was the highest in the Orajõe area, where the frequency of higher plants and some filamentous algae was higher in wrack samples than in the sea (Table 4). The frequent occurrence of higher plants in beach wrack samples, compared to the data collected by the diver, was also recorded at the end of the growing season.

5. Discussion

Sampling of beach wrack and sampling of the seabed phytobenthic community yielded very similar results, indicating that it is possible to use beach wrack for assessing the species composition of the adjacent sea area. In the autumn samples, the similarity between the two sampling methods was somewhat less than in spring and summer because of the greater occurrence of vascular plants in beach wrack samples compared to the material collected from the seabed. Although hydrodynamic variability is higher in autumn and more biological material is cast ashore, the relatively large proportion of rapidly decomposing filamentous algae makes these samples less suitable for monitoring; analysis of mid-season data is therefore recommended. In spite of a number of statistically significant relationships between the hydrodynamic variables and the beach wrack found (Table 2, Figure 4), these relationships cannot be used for predicting the qualitative aspects of the composition of the biological samples. One reason for this is that the relationships were not similar in all the areas; another reason is the possible influence of seasonality.

The relationships at Kõiguste were stronger (e.g. Figure 4), where the phytobenthos biomass was the highest. The relationships at Sõmeri were mostly similar to but weaker than those at Kõiguste, whereas Orajõe often displayed mixed or unclear relationships with hydrodynamics. For instance, the relationships between frame coverage and wave height was positive at Kõiguste, weak (or mixed) at Sõmeri and negative at Orajõe. According to Viikmäe & Soomere (2014), a straight coastline seems to have less chance of receiving material. However, it appears that the straight coastline of Orajõe mostly receives its wrack in regular hydrodynamic conditions and occasionally due to currents, while high sea level and wave (swash) events may even carry some of the wrack material back to sea. We should bear in mind that the Orajõe region has the scarcest bottom vegetation and also showed somewhat larger discrepancies between the two tested hydrobiological sampling methods (Table 4).

The stronger relationships with waves and sea level variations and the weaker ones with currents justify the use of wrack samples for assessing species occurrences in the sea. The formation of beach wrack requires a certain amount of wave activity to rip the organisms from their substrate and then to cast them up on to the shore. On the other hand, weak correlations with currents show primarily that the alongshore currents in the practically tideless Estonian coastal sea are meteorologically driven and not strong enough (Figure 3) to compete with waves in ripping off the benthos. Also, the current in the Estonian coastal sea typically reverses on average once every 0.9 days, and the current direction is sustained for more than five days less than five times per year (Figure 3b; Suursaar et al. 2012). The absence of long seasonal or tidal currents and the infrequent occurrence of any other kind of persistent circulation ensure that the material on the beach originates in the adjacent sea areas. On the other hand, in such semi-enclosed boreal seas, high sea level and wave events occur on an almost regular basis at least every 10–30 days, less often in summer and more frequently in autumn, providing fresh material for the beach wrack (see also Filipkowska et al. 2009). We can also conclude that it is advisable to skip long-lasting calm weather conditions and go for beach wrack sampling after a storm. In general, the stronger the storm event, the richer the wrack strip (Figure 4). As in tidal seas, the wrack statistically tends to be more abundant during spring tides than neap tides (e.g. Ochieng & Erftemeijer 1999).

In general, the effectiveness of the various sampling methods (e.g. SCUBA diving, drop down and hand-held underwater video cameras, statistical modelling; see e.g. Bučas et al. 2009) differs somewhat. We believe that beach wrack sampling is both efficient and cost-effective. Indeed, we mostly found more macrophyte species from beach wrack samples compared to data collected by divers or using underwater cameras (Table 3). The higher species diversity recorded in beach wrack samples than in seabed samples can be explained by the higher accuracy of laboratory analysis of beach wrack samples compared to the in situ visual assessment of seabed communities. Additionally, some better floating specimens (e.g. *Zostera marina* L., *F. vesiculosus*) might have been carried from more distant areas. *Zostera marina* was found in the beach wrack samples but not in the seabed samples in all areas. *Z. marina* was previously found in the Kõiguste area (Möller & Martin 2007). In the Sõmeri area, the closest known site of *Z. marina* is 7 km and at Orajõe 15 km away (database of the Estonian Marine Institute). Also, the higher abundance and occurrence of *F. vesiculosus* in beach wrack samples compared to the nearshore area indicate that the plant material in the wrack originates from a somewhat larger sea area than the very narrow in situ sampling transects. Therefore, sampling of beach wrack can give a more accurate estimate of species diversity than underwater visual observation in heterogeneous areas. As diving is time-consuming and expensive, only a limited number of diving transects are sampled during ordinary biodiversity assessments (e.g. environmental monitoring, inventories of marine protected areas). However, the small number of transects may not be sufficient for adequately assessing the biodiversity of large and heterogeneous marine areas.

Sampling of beach wrack has the potential to improve biodiversity assessments as the method enables biodiversity information to be obtained from much larger areas compared to the sparse in situ seabed sampling. Variation of species occurrences between methods in the samples described can be explained by the different distribution of vegetation along the wrack line or sea bottom. The variations in the data sets of beach cast samples were smaller as the species originating at different depths were bunched together by the nearshore wave action. Data collected by the diver have a greater variation of species distribution at different depths along the depth gradient of the transect.

6. Conclusions

Coherence between the samples of beach wrack and submerged vegetation is hydrodynamically possible because (1) the alongshore currents in the practically tideless Estonian coastal sea are meteorologically driven and generally niether persistent nor strong; the material on the beach originates from the adjacent sea areas; (2) high sea level and wave events occur on an almost regular basis at least every 10–30 days, providing fresh beach wrack material. In general, the stronger the storm event, the richer the wrack. However, the relationships between wrack-forming hydrodynamic factors were somewhat site-dependent. For instance, at the more indented Kõiguste and Sõmeri areas, the relationships with waves were strong and positive, but mixed at the exposed and straight coastal section at Orajõe. Also, among the study sites, the Kõiguste area had the highest macrovegetation biomass and coverage, whereas Orajõe had the scarcest vegetation based on beach wrack samples. The influence of water circulation on wrack samples is brought to bear by the coastline configuration, i.e. it depends on how easily and from which side of the site the material gets trapped.

The study demonstrates that beach wrack sampling can be considered as an alternative cost-effective method for describing the species composition in the nearshore area and for assessing the biological diversity of macrovegetation. In fact, we even found more species from beach wrack samples than from the data collected by divers or by using a 'drop' video camera. Although hydrodynamic variability is higher in autumn and more biological material is cast ashore, the similarity between the two sampling methods was greater in spring and summer, making these seasons more suitable for such assessment exercises. However, the method, outlined as a case study in the Baltic Sea, can be somewhat site-dependent and its applicability in other areas of the Baltic Sea should be tested.

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